CR-195507 Texas Univ. Austin NASW-4435

IN-54-CR

204227

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MEMORANDUM

To: Dr. Busch-Vishniac

From: Li-Dai Lu

Date: June 2, 1993

Re: NASA Project 1 - Full-body Dynamometer

The specification and the function structure for the full-body dynamometer is based on available literature and information supplied by the teaching assistants. However, some of the journals were not available in the library. In addition, personal research was conducted to uncover as much information as possible in the two week period. The report following the memorandum contains discussions of the specification and the function structure for the full-body dynamometer. A tabular form of the specification and the complete function structure diagram are also included

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Specification and Function Structure for the Full-body Dynamometer

Introduction

In space, where the body does only a fraction of work it does on earth, muscle atrophy is a major concern. The bones and the muscles will begin to deteriorate after a short stay in weightlessness. Bone decalcification appears to be a major problem with extensive living in microgravity. Resistance exercise is not only essential to prevent muscle atrophy in space, it also helps to keep bone decalcification in check. For a space station, where the astronauts are expected to live for months at a time, exercise is especially important. Experts recommend about an hour and a half to two hours of exercise per day to keep the muscles in good condition in microgravity [Stine, 1985]. The exercises will not only keep the astronauts in excellent physical condition, it will also make it easier for them to readjust to earth's gravity on return.

The stationary bicycle and the treadmill have been the astronauts' primary sources of exercise since the 1970s [Shipman, 1989]. The major problem with both the stationary bicycle and the treadmill is that while they may keep the leg muscles from deteriorating in microgravity, they do little for muscles in the upper body. The National Aeronautics and Space Administration (NASA) is currently developing a full-body dynamometer (FBD), which will provide the astronauts with a full-body workout. It will also test the astronauts for muscle atrophy and rehabilitate the weakened muscle. This report presents the specification and the function structure for the FBD.

The Specification

The complete specification list is presented in Table 1. The individual specifications will be discussed in detail in the following sections. The discussion will include explanations and provide means of verification for each specification.

Geometry. The maximum dimension for the proposed full-body dynamometer is limited to eight feet in length, width and height by NASA [Klute, 1993]. The dimension restriction is mainly due to the limited space availability in space stations. Since the space shuttle will be the primary transportation system for the space station [NASA, Space Station, 1988], the FBD will also need to be able to fit into the shuttle's cargo bay. It may be a good idea to consider designing the FBD with assemblage in mind, since the space shuttles have limited cargo space. The modular design will make the assembling of the FBD easier and make future expansion possible. Once arrived at the space station, the FBD is to be secured to the station. The means and procedure of securing the FBD will conform to NASA regulations.

Kinematics. The tests and exercise patterns that the dynamometer must perform are listed in this section of the specification. Because the tests and exercise patterns involve almost all the major joints of a human body, the FBD needs to be able to allow a full range of motion, from 15 degrees for wrist abduction to 190 degrees for shoulder flexion. The data are taken from a 1983 report by the Human Factor Society [Sanders, 1989]. If there are other more accurate or recent anthropometric data, the specification can be modified to suit the current need.

Forces and Energy. The maximum weight and torque of the FBD are given by NASA to be 800 pounds and 450 foot-pounds, respectively [Klute, 1993]. The weight restriction is necessary because of the space shuttle's payload limitation. NASA also specifies the power source of the FBD to be 160 volts DC and the maximum power consumption to be 1 kilowatt. The power consumption needs to be limited so as not to interfere with other vital operations of the space station. Another important facet that needs to be considered is the launch forces and vibration. The space shuttle's fuel rocket boosters and rear engines are designed in such a way that the shuttle will experience a 3 g gravity load, as oppose to 8.1g on earlier manned flights [NASA, Space Shuttle, 1987]. The launch force and vibration analysis for the FBD can be done by prototype testing and/or simulation.

Materials. The material for the full-body dynamometer must be chosen carefully. First, the material must be compatible with microgravity environment. Material properties may change in microgravity environment and therefore need to be tested. In a controlled environment such as the space station, it is very important that the material is non-flammable and emits no harmful contaminants. In addition, the dynamometer most likely will be in contact with human skin. It may be advisable to make sure the material chosen is hypo-allergenic.

Signals. For the FBD to analyze its user's performance, it will need the user's past physical data and statistics. Therefore, the FBD needs to have the capability of storing historical statistics and data of its users. It will also need to be able to update the user's statistics for future reference. The storing and updating of the user statistics can be verified by computer code testing and prototype testing.

More fundamentally, the user needs means of communication with the FBD to begin an exercise program. The user will need to input his function choice (testing, strengthening, or rehabilitation), desired resistance, and his identification so the FBD can locate his statistics for evaluation. Conversely, the FBD also must inform the user of his progress. If the user has lost 10% of his strength, the FBD needs to alert the user about possible muscle atrophy. The input and output functions will require signal conditioning tests to ensure its proper functioning.

To simplify some of the work on the FBD, it may be feasible to connect the FBD to the space station's computer. This approach will save some computation time and reduce the complexity of the design. In addition, 2% measurement accuracy should be a reasonable demand on the FBD. A signal conditioning test is also a good way of verifying this specification.

Safety and Ergonomics. In the past, the astronauts had to strap themselves to the stationary bicycle or the treadmill to get a good workout. The FBD will also need a safe way of securing the user to the machine. On the other hand, there is also a need for emergency release or breakaway in case of machine malfunction. Another safety issue is that the FBD should be shielded from electromagnetic and electric fields in space and other equipment in the station. The FBD also should not interfere with other equipment in the space station by emitting its own electric or electromagnetic fields. Radiation measurement should be taken to verify the above specification. The last specification in safety calls for no sharp edges and protruding surfaces on the FBD. The specification will help to minimize injuries in space.

The FBD needs to be adjustable to accommodate 95th-percentile humans to accommodate ranges of body dimensions. The data for the 95th-percentile human can be found in recent anthropometric data. To verify this specification, prototype testing on users can be done to collect the necessary data for possible modification. In addition, prototype testing on users can provide a way to measure 'comfort.'

Transport and Operation. When designing the full-body dynamometer, the operating and transporting environment of the machine needs to be considered. The operating pressure range for the FBD will correspond to the regulated space station pressure between 10.4 and 14.7 pounds per square inch [NASA, Space Station Freedom, 1992]. The cargo bay pressure of the space shuttle closely follows flight atmospheric pressure, which ranges from 0 pounds per square inch to 15 pounds per square inch [NASA, Space Transportation, 1977]. The cargo bay temperature is carefully controlled by purging while the shuttle is still on the ground. Once the shuttle is air-borne, however, the cargo bay temperature may be as high as 180° F [NASA, Space Transportation, 1977]. In space, the heating of payload components will depend on the thermal, thermophysical, and geometric characteristics of each component. Other influencing factors include launching date and hour, shuttle orientation, and orbital altitude. A detailed analysis will be necessary to decide the precise transporting temperature range. In the space station, the FBD will operate in room temperature regulated by the space station.

The main functions of the FBD are muscle strength testing, muscle atrophy rehabilitation, and muscle strengthening. Since all of FBD's functions involve resistance, it is important that the resistance supplied by the machine not fluctuate and result in jerky motions. Extensive prototype testing will be necessary to ensure proper operation of the FBD.

The noise generated by the FBD should not cause annoyance for the users. The recommended range is among 45 and 65 decibels. Forty-five decibels correspond to normal conversation between two people ten feet apart. Sixty-five decibels, on the other hand, will require two people to stand two feet apart and raise their voices [Burgess, 1986]. For the user's convenience, the user should be able to master FBD operations in one or two hours. To increase the efficiency of the FBD, the required set-up time between exercises should not be longer than 90 seconds.

Maintenance. Maintenance planning is an important consideration in designing sophisticated equipment such as the full-body dynamometer. Regular preventive maintenance services will not only save money in the long run, it will also increase the life span of the machine, possibly exceeding the expected life of 30 years. Careful maintainability testing and evaluation, which include tests and evaluation in the machine's accessibility in repair, repair, removal, and inspection, must be performed to ensure a sensible maintenance procedure and schedule. A recommended maintenance schedule is two hours per month. In coming up with a maintenance schedule, the designer must also consider the limited resources of a space station. If a component of the machine needs repair, the astronauts should be able to repair the component with available tools and equipment in the space station.

Production, Quality Control and Costs. The cost of the FBD is limited by NASA to be 500 thousand dollars. Economic analysis will need to be performed to ensure the development is within the budget limitation. The designer also must pay attention to the production regulations set up by the federal government and NASA.

Table 1

Specification for Full-body Dynamometer		
D W	Requirements	Verification
	Geometry	
D	Maximum dimensions: 8' x 8' x 8'	Dimension measurement
D	Follow NASA requirements for securing unit to space station	Inspection
D	Modular design	Inspection
	Kinematics	
D	Allow full range of motion (15° - 180°)	Prototype testing
D	The Exercise and Testing Patterns: Knee Extension/Flexion Sitting Extension/Flexion Supine Extension/Flexion Prone Shoulder Flexion/Extension Supine Abduction/Adduction Side Flexion Abduction/Extension Adduction Supine External/Internal Rotation Neutral External/Internal Rotation 45° Abducted External/Internal Rotation 90° Abducted External/Internal Rotation 90° Flexion Sitting Flexion/Extension Sitting Abduction/Adduction Sitting Elbow Flexion/Extension Supine Flexion/Extension Sitting Ankle Dorsi/Plantar Sitting Straight Knee Dorsi/Plantar Sitting Flexed Knee Dorsi/Plantar Supine Straight Knee Dorsi/Plantar Supine Flexed Knee Dorsi/Plantar Prone Straight Knee Dorsi/Plantar Prone Flexed Knee Dorsi/Plantar Kneeling	Prototype testing

D W	Requirements	Verification
	Eversion/Inversion Wrist Flexion/Extension Supinated Flexion/Extension Pronated Radial/Ulnar Deviation Supination/Pronation Hip Abduction/Adduction Flexion/Extension Flexion Adduction/Extension Abduction External/Internal Rotation Prone Back Flexion/Extension Standing Flexion/Extension Sitting	
	Forces	
D	Maximum weight: 800 lbf.	Weight measurement
D	Maximum design torque: 450 lbf-ft.	Torque evaluation
D	Withstand launch forces and vibration	Prototype testing and simulation
	Energy	
D	External power source: 160 V DC	Voltmeter
D	Maximum power consumption: 1 kW	Power meter
	Material	
D	Compatible with micro-gravity environment	Material testing
D	No off-gassing of harmful contaminants	Material testing
D	Non-flammable or least-flammable material	Material testing
D	Hypo-allergenic material	Material testing
	Signals	
D	Store historical data and statistics of users	Program testing
D	Update historical data and statistics of users	Program testing
D	Input: Desired functions (testing, strengthening, or rehabilitation) Desired resistance (for strengthening) User identification	Signal conditioning analysis
D	Output: Strength gain/loss Alarm user when muscle strength drop within 10%	Signal conditioning analysis
W	Interface with station computer	Signal conditioning analysis

D W	Requirements	Verification
W	Measurement accuracy: ±2%	Accuracy evaluation
	Safety	
D	Emergency release/breakaway	Prototype testing on users
D	Shielded from electromagnetic and electric fields	Radiation measurement
W	No sharp edges and protruding surfaces	Prototype testing
	Ergonomics	
D	Safe means of securing the user to the machine	Prototype testing on users
D	Machine adjustable to 95 percentile human	Prototype testing on users
W	Comfort	Prototype testing on users
	Production and Quality Control	
D	Conform to federal and NASA regulations for defense industry	Audit
	Transport & Operation	
D	Pressure range: Storage: 0 - 15 psia Operation: 10.4 - 14.7 psia	Pressure gauge
D	Temperature range: Storage: 45 - 180° F Operation: Regulated room temperature	Thermometer
D	Resistance supplied by the unit should not fluctuate	Prototype testing
D	Muscle strength testing (fixed and constant resistance)	Prototype testing
D	Muscle strengthening (user-specified strength)	Prototype testing
D	Muscle atrophy rehabilitation (user-specific programs)	Prototype testing
W	Noise control: 43 - 65 dB	Sound level meter
W	Operations can be learned in 1 - 2 hours	Prototype testing
W	Maximum time between exercises: 60 - 90 seconds	Prototype testing
	Maintenance	
D	MTTF: 30 years	Component life cycle analysis
W	Preventive maintenance: 2 hrs/month	Maintainability evaluation

D W	Requirements	Verification
W	Repairable in space with available tools/equipment	Part selection and testing
	Costs	
W	Manufacturing cost: <= $500,000.00	Cost analysis

Function Structure

A function structure has been developed for the full-body dynamometer based on the specification and is provided in Figure 1. The following discussion will go through a complete FBD operation cycle.

The user will begin his exercise or test routine by securing himself to the FBD and power up the machine. He then needs to select a function (muscle testing, strength training, or rehabilitation), which will inform the FBD to prepare for the specified function. In addition, the user needs to input his identification so the FBD can locate the user's past statistics. The FBD will then change the user's energy to forces and movements, which the FBD will react with corresponding resistance. The torque and the velocity of the movement are then measured. The signals are conditioned or amplified for comparison with the user's past statistics. The data is then updated. At this point, the FBD will determine whether the user has lost more than ten percent of his strength. If so, the FBD will inform the user on how much strength is lost and recommends rehabilitation. The user then can choose either to continue his routine or to stop. If he chooses to continue, the FBD will prompt for the next exercise and wait for the user to finish setting up for the next exercise. Then the entire cycle begins again. If the user decides to stop, the FBD will display his progress-to-date and let the user leave.

Conclusion

The specification and function structure presented above are preliminary suggestions based on available information and literature. When more information becomes available, the specification will need some changes and revisions. The function structure will also need some refinement when more specific demands on the design surface. For now, the specification and function structure presented in this document represent a fairly complete picture of the expectations for the full-body dynamometer.

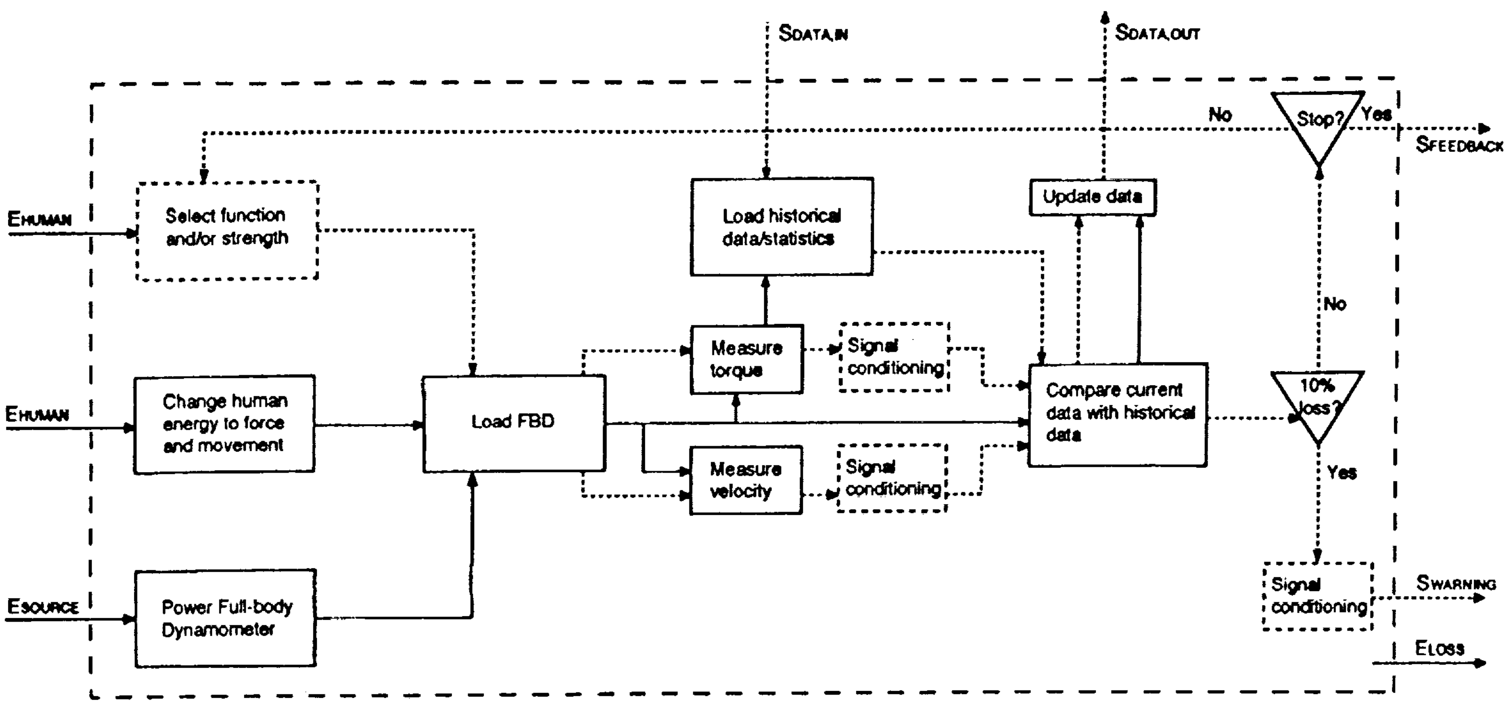

Figure 1. The Function Structure for the Full-body Dynamometer

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